Characterizing Willamette Valley Soil Moisture and Grapevine Response under Drying Seasonal Conditions

Patricia A. Skinkis, Mathew R. Lange, and R. Paul Schreiner

Summary (Final Report)

Soil moisture, weather data, and vine growth were measured during three growing seasons (2020-2022) in one vineyard containing three soil types. Pinot noir of the same rootstock and vine age were grown in three soil types, including sedimentary soils (Dupee), volcanic soils (Saum), and glacial flood deposit soils (Woodburn-Willamette). Soil probes measured volumetric water content, soil temperature, and electrical conductivity for each soil type at depths of 18- and 36-inches under-vine and in the middle of the alley between vine rows. Soil monitoring was continuous from January 2020 to December 2022. Coming into each growing season, soil moisture was at field capacity and remained relatively consistent through much of spring each year. However, the start of soil moisture decline varied each year depending on rainfall patterns. Soil moisture decline began in mid-June 2020, in early to mid-April 2021, and in mid-June 2022. There was a gradual soil moisture decline throughout summer each year when there was little to no precipitation. All years had similar annual and seasonal precipitation, although the timing of rainfall varied, with the driest spring in 2021 and the wettest in 2022. Soil moisture was reduced more at the 18" depth than at the 36" depth, and the lowest soil moisture was recorded in Woodburn-Willamette (sedimentary soil) for all three years. Vines grown in Woodburn-Willamette soil had the greatest vegetative growth and fruit yield for all three years compared to Dupee and Saum, both of which had similar vine vegetative growth and yield. Interestingly, the largest vines and greenest canopies were in the Woodburn-Willamette soil that had the lowest soil moisture, suggesting that the higher vigor vines may have required more water from the soil profile, than in the other two soil types at the depth measured. Evaluation of the soil profile in December 2022 revealed that Woodburn-Willamette had a deeper soil profile, allowing for rooting below 36" and access to greater soil volume and soil moisture at depths below where our sensors were placed. Leaf water potential and leaf gas exchange measures further indicated that Woodburn-Willamette vines were under less stress than Saum and Dupee. Despite variable vine water status, berries of vines in each soil type reached commercially acceptable ripeness each year. Saum consistently had the most advanced berry ripeness with the highest total soluble solids and pH and the lowest titratable acidity, potentially due to a more rapid phenological development. However, Dupee had the greatest sugar/ berry, likely due to its higher level of sustained water stress. Findings from this three-year study show that soil type plays a pivotal role in water availability, plant growth, yield, and fruit chemistry. This highlights the importance of understanding site-specific characteristics and creating a management program that is more tailored to the individual vineyard soil characteristics.

Unified Grant Management for Viticulture and Enology
Annual Report (Final) – January 2023

1. **Project Title and UGMVE proposal number**: Characterizing Willamette Valley Soil Moisture and Grapevine Response under Drying Seasonal Conditions (2021-2306)

3. Principal Investigator: Patricia A. Skinkis, Professor & Viticulture Extension Specialist, Department of Horticulture, Oregon State University, 4017 ALS Bldg., Corvallis, OR 97331, ph.: 541-737-1411, email: Patricia.Skinkis@oregonstate.edu.

Co-PI: R. Paul Schreiner, Research Plant Physiologist, USDA-ARS Horticulture Crops Research Lab, 3420 NW Orchard Ave, Corvallis, OR 97330. ph.: 541-738-4084, email: Paul.Schreiner@usda.gov.

4. Cooperators:
Andy Gallagher, Soil Scientist and Consultant, Red Hill Soils, Ph: 541-740-9508, Email: avg@redhillsoil.com.

Chad Vargas, President, NewGen Vineyard Services, Ph: 503-572-4807, Email: chad@newgenvs.com.

5. Objectives and Experiments Conducted to Meet Stated Objectives:

Objective 1. Characterize soil moisture conditions throughout the season among different soil types common to Willamette Valley wine grape production.

This research was conducted in a commercial vineyard in Newberg, OR, with three soil types common to vineyards in the Willamette Valley, including soils derived from volcanic rock, sedimentary rock, or glacial flood deposits. The vineyard was mapped prior to planting in 2008 and includes the following associated soil types: Dupee (sedimentary soil), Saum (volcanic soil), and Willamette-Woodburn (glacial flood deposits). All blocks are located on low elevation foothills and are within a narrow range of elevation (263-369 ft asl). The vineyard is planted to Pinot noir (Pommard clone) on 101-14 rootstock with 5 ft between vines and 6.5 ft between rows in north-south oriented rows.

Soil moisture was measured within vineyard blocks of each soil type. Sensors and dataloggers were installed on 8 Jan and 9 Jan 2020. Sensors were placed under-vine (in-row) and in the mid-alleyway (between rows) at a depth of 18 in and 36 in (45.7 cm and 91.4 cm) using 12 cm soil water reflectometer sensors (CS655, Campbell Scientific, Logan, UT). These sensors measure soil volumetric water content, temperature, and electrical conductivity. Two soil-monitoring locations were positioned within each soil type. A weather station (ClimaVUE50, Campbell Scientific, Logan, UT) was installed at the vineyard to provide air temperature, precipitation, solar radiation, relative humidity, and wind speed. Soil and environmental data were measured every 15 minutes and summarized as hourly and daily means. Data were compared with vine phenology, vine growth, and physiological measures collected during each growing season as outlined in Objective 2.

Objective 2. Determine vine water status, growth, and berry development response to weather and soil moisture conditions throughout the season among vines growing in different soil types.

Plant growth and vine physiological responses were measured on 36 vines distributed in close proximity to each soil-monitoring site (within the same row and two rows flanking the soil moisture sensors). There were two soil monitoring sites within each soil type. Vines were flagged and used for repeated measures as appropriate to pair site and soil data for analysis. Dates of vine growth stages were recorded for key phenology stages, including bud break, bloom, véraison, and harvest using the modified E-L scale (Coombe 1995). This data was compared to the heat unit data from the on-site weather station. Early season shoot growth was measured weekly from ~6" shoot growth and up to bloom. Whole vine leaf area was measured at bloom and véraison by collecting whole vine shoot count and shoot leaf size data using a non-destructive leaf area method as described by Navarrete (2015). Briefly, shoot length and leaf area were measured on two shoots per vine within 9 panels (trellis post to trellis post) amongst the 36 vines. Dormant pruning weights were measured at the end of the growing season. The combined in-season growth data and pruning weights were evaluated with weather and soil data and comparisons across soil types.

Vine water status was measured in two ways each season, including leaf water potential and leaf gas exchange. Leaf water potential was measured using a Scholander pressure chamber (model 600, PMS Instruments, Albany, OR). Monitoring began once full canopy was achieved (post-bloom) and continued pre-harvest, as long as conditions were conducive for measures (clear, sunny days). Measures were taken midday on fully sun-exposed leaves in the mid-canopy of data vines. Leaf gas exchange was measured using an infrared gas analyzer (LI-6400 XTR, LiCor Biosciences, Lincoln, NE) to measure photoassimilation and stomatal conductance, starting once the canopy was fully developed (post-bloom). Both leaf water potential and gas exchange data will help us understand the water status in the different soil types, as they measure different physiological parameters and are being measured on the same day. Water status data are being compared with the weather and soil moisture data obtained from the same dates.

Since soil moisture influences vine nutrition, we quantified mineral nutrient status of tissue samples (leaf and petiole) at bloom and véraison. Samples were analyzed for macro- and micronutrient concentrations by Fruit Growers' Lab, who donated the service.

To determine the impact of soil type and water availability on yield and crop development, yield components, including fruitfulness and berry development were measured. Fruitfulness (inflorescences per shoot) were measured after shoot thinning and before bloom. Vines were shoot-thinned and managed per normal standards of a vertically shoot positioned canopy. Uniform thinning to production standards of the vineyard were used for all three blocks, which was minimal to none during the three seasons. A Pinot noir berry development curve and crop estimation model has been developed for the region (Skinkis and McLaughlin 2022). Berry development was to determine whether this model works under different soil types with the intent to validate or modify the model based on potential differences due to soil type. To do this, 20 clusters were collected from each soil type, starting at 22 d post 50% bloom and continue weekly or twice weekly until harvest, averaging 16 samples per year. We measured cluster weight, berry count, rachis weight, rachis length, and berry weight during each sampling. Whole vine cluster counts and yield will be measured on the data vines at harvest, and nine, 10-cluster samples were collected from each soil monitoring location at harvest. Half of each sample (5 clusters) were analyzed for cluster weight, berry count, berry weight, and rachis length. Berries were pressed to juice and measured for TSS, pH, and TA. An aliquot of juice for each berry sample was frozen at -20°C until analysis for yeast assimilable nitrogen (YAN) by assays for ammonia (r-Biopharm) and alpha-amino acids (Dukes and Butzke 1998). The other 5 clusters were frozen at -80℃ until analysis for total anthocyanin using the pH-differential method (Lee et al. 2005), total phenolics using the Folin-Ciocalteu method (Waterhouse, 2002), and total tannins using the methyl cellulose precipitation method (Sarneckis et al., 2006).

6. Summary of Major Research Accomplishments and Results by Objective

Objective 1. Characterize soil moisture conditions throughout the season among different soil types common to Willamette Valley wine grape production.

Soil volumetric water content at the 18" depth was consistently lower than the 36" depth in both the vine row and alley, regardless of soil type during all three years (Figure 1a – 1i). Soil moisture was lower in the alleyway for both the Saum and Woodburn-Willamette, while the Dupee had lower soil moisture in the vine row. In all three years the Woodburn-Willamette soil had the lowest soil moisture compared to the other two soil types in late spring to summer, with volumetric soil moisture ranging from 0.2 – 0.5 m^3/m^3 less than in the other two soils. The largest difference in soil moisture was during late summer in the alleyway at 18", with volumetric soil moisture averaging 0.75 m^3/m^3 less in the Woodburn-Willamette than in the other two soils. Dupee and Woodburn-Willamette soil had more rapid soil moisture decline during mid-late summer (Figure 1a-1i). Typically, soil moisture dry-down began in late April. However, in 2022 late spring precipitation kept soil moisture levels at field capacity until mid-June. Although both growing seasons had comparable seasonal and annual rainfall (Table 1), the timing of precipitation varied, with 2021 being the driest from bud break to bloom, and 2022 being the wettest.

Objective 2. Determine vine water status, growth, and berry development response to weather and soil moisture conditions throughout the season among different soil types.

Vine growth. There were visible differences in vine growth throughout the study. Vine growth was measured using shoot growth during spring, leaf area in summer, and dormant pruning weights in winter. While there were no differences in leaf area, pruning weights in the Woodburn-Willamette were nearly 2-fold greater than those in the other soils each year (Table 2). The larger canopy growth of vines in Willamette-Woodburn soil may have created a greater water demand from the soil, thereby reducing the total soil volumetric water content measured in the 18-36" soil depth compared to the other soil types.

Vine nutrient status. Leaf blades and petioles were analyzed for macro- and micronutrients at bloom and véraison each year. Vines growing on Willamette-Woodburn soils had higher leaf blade and petiole nitrogen (N) than the other two soil types for both bloom and véraison. Vines had sufficient N levels at bloom for all three soil types. However, Saum vines were nearing the limit of sufficiency by veraison in 2020 and 2021 (Table 3). It is not surprising that the Willamette-Woodburn vines had higher N, as overall growth was greater as observed with the dormant pruning weights. Tissue phosphorus and potassium levels were similar between the three soil types and were within the sufficient/healthy range for both bloom and véraison (data not shown).

Water status. Water status was measured as leaf gas exchange and leaf water potential throughout summer. On average, measurements were taken on seven dates from mid-July to early September. Mean leaf water potential ranged from -0.61MPa (no stress) to -1.55 MPa (severe stress) during the observation period. Vines were at mild stress levels or greater for nearly all of the dates each year, with Dupee vines having the lowest leaf water potential readings, indicating the most water stress (Figure 2a-2c). While Woodburn-Willamette and Saum had similar leaf water potential measures for much of the summer, the leaf gas exchange data indicated that vines growing in Woodburn-Willamette soils were not stressed based on high photoassimilation and stomatal conductance rates throughout the entire summer. Dupee vines had the lowest photoassimilation and stomatal conductance, as expected with the lowest leaf water potential. It is likely that vines in Dupee and Saum reduced vine growth as they experienced sustained water stress during the summer, which is evidenced by lower pruning weights. Conversely, vines in Woodburn-Willamette were not perturbed by the dry summer, suggesting that the vine roots had adequate access to soil water.

Berry development. The berry development curve followed the curve described by the Skinkis Lab in previous years (Skinkis and McLaughlin 2022). There were minor differences by soil type for berry weight during the study. Further analysis continues with this 3-year data set to determine differences in berry development relative to soil water deficit and plant water stress. type for berry weight during the season.

Yield and yield components. Whole vine yields were measured at harvest in all three years. Yield weights and cluster samples were taken from 9 panels of vines (4 vines each) in each of two soil moisture monitoring locations. The average yields varied by year, with 2020 and 2021 being low set years and 2022 being impacted by the spring freeze. Therefore, yields were never amended by cluster thinning and represent the actual yield (Table 2). Cluster weight varied across all years and soil types, with the lowest weight being recorded in Dupee in 2020 (69 g) and the highest in Woodburn-Willamette in 2022 (122 g). Berry weights varied more by year than soil type, with the lowest values being seen in 2020 (0.71 g) and the highest in 2022 (1.2 g). Woodburn Willamette had the greatest average yield, and this was attributed to greater cluster size and berry weight.

Berry composition. Basic ripeness at harvest was quantified for fruit samples collected from each of 9 panels of vines in each soil sensor location at harvest each year. Fruit from vines growing in Woodburn-Willamette had lower total soluble solids than the other two soil types (Table 4). Vines growing in Saum soil had the most advanced maturity with highest TSS, highest pH, and lowest TA each year. Woodburn-Willamette and Saum had similar pH and TA. Despite greater water stress measured in the Saum and Dupee vines, the berries were able to reach commercially acceptable ripeness by harvest. By looking at TSS alone, it appears that water stress did not limit but possibly enhanced the ripening process, which is the conventional wisdom in illiciting some late season drought stress to spur on ripening. However, for two of the three years, Woodburn-Willamette had higher sugar per berry compared to the other two soil types yet lower TSS (Table 4). Berry phenolic assays conducted on whole berry extracts to quantify total anthocyanin, phenolics, and tannin concentrations did not show a clear difference by soil type. Plant water stress and/or changes in canopy vigor (and light exposure) have been known to increase phenolics, namely anthocyanin. However, clear differences were not found between soil types (data not shown). In alignment with greater tissue N in Woodburn-Willamette, the fruit at harvest had higher YAN than berries from the other two soil types.

As of this reporting, data analysis is underway but not yet complete. However, the project data will be analyzed and prepared into a manuscript for publication in spring/summer 2023.

7. Outside Presentations of Research

Information from this research has been shared with the industry, students, and academic peers during 2020-2022 through several venues, including the Oregon Wine Research Institute Grape Day in spring 2022, several Oregon wine industry seminars, and two posters at the American Society of Enology and Viticulture National Conference in June 2022. The PI has informed others about project status and results through industry tech group meetings with and through social media outlets, including the Skinkis Lab Instagram postings @patty.skinkis.

8. Research Success Statements

This project is generating regionally specific information on soil moisture and seasonal grapevine growth and development that will help industry understand how to manage soil and water resources that impact vine growth and productivity. For example, they will better understand how and when to manage the vineyard floor (if dry-farmed) or when to apply water (if irrigated). The information also builds upon the regional data from co-PI projects that will improve yield, nutrient, and vineyard floor management guidelines for the region. This study also provides the foundational information necessary to fine-tune future research projects in vineyard soil management.

9. Funds Status

Funds from this grant were used to support Skinkis Lab Personnel, including a portion of one faculty research assistant in year 1 (Annie Chozinski) and one 0.49 FTE graduate research assistant (Mathew Lange) in years 2 and 3. These personnel-maintained sensors, collected data at regular intervals, collected vine growth and physiology data. They also provided support in data organization, analysis and reporting. Funds were also used to support undergraduate research assistants in 2020 and 2021 and one exchange graduate student research assistant during spring-fall 2022. Funds were also used to purchase all the required soil moisture monitoring sensors, data loggers, weather station, and associated supplies for the vineyard installation of monitoring sites, and transportation to the commercial site where the work is being conducted. Funds have also been used for all the lab consumables and assays needed for fruit composition analyses.

10. Literature Cited

Coombe B. 1995. Growth Stages of the Grapevine: Adoption of a system for identifying grapevine growth stages. Australian Journal of Grape and Wine Research 1:104–110.

Dukes BC and Butzke CE. 1998. Rapid determination of primary amino acids in grape juice using an *o*-phthaldialdehyde/N-acetyl-L-cysteine spectrophotometric assay. Am J Enol Vitic 49: 125-134. https://www.ajevonline.org/content/49/2/125

Lee J, Durst RW, and Wrolstad RE. 2005. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: Collaborative study. J AOAC Intl 88:1269-1278.

Lorenz DH, Eichhorn KW, Bleiholder H, Klose R, Meier U, and Weber E. 1994. Phänologische Entwicklungsstadien der Weinrebe (*Vitis vinifera* L. ssp. *vinifera*). Vitic Enol Sci 49: 66–70. http://www.gartneriraadgivningen.dk/upl/website/bbch-skala/scaleBBCH.pdf

Navarrete AM. 2015. Characterizing grapevine canopy architecture. MS Thesis, Oregon State University, Corvallis. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/9s1619855?locale=en

Sarneckis CJ, Dambergs RG, Jones P, Mercurio M, Herderich MJ, and Smith PA. 2006. Quantification of condensed tannins by precipitation with methyl cellulose: Development and validation of an optimized tool for grape and wine analysis. Austral J Grape Wine Res 12:39-49. http://onlinelibrary.wiley.com/doi/10.1111/j.1755-0238.2006.tb00042.x/full

Skinkis PA and McLaughlin KR. 2022. Pinot noir crop estimation method allows growers to estimate yields earlier than lag phase. Catalyst: Discovery into Practice:catalyst.2021.21005. https://doi.org/10.5344/catalyst.2021.21005

Waterhouse AL 2002. Polyphenolics: Determination of total phenolics, p. 463-470. In: R.E. Wrolstad (ed.). Current Protocols in Food Analytical Chemistry. Wiley, Hoboken, N.J.

Tables

Table 1. Seasonal and annual precipitation in Newberg, OR during 2020-2022

	Annual Precipitation (1 Jan – 31 Dec)		Seasonal Precipitation (1 April – 31 Oct)	
Year	Inches	mm	Inches	mm
2020	40.7	1035	11.3	287.3
2021	38.7	983	10.1	255.5
2022	42.2	1072	17.2	436.6

Table 2. Vine growth and yield of Pinot noir growing in three soil types during three growing seasons (2020-2022)

	Soil Type	Bloom leaf area (m^2/vine)	Véraison leaf area (m^2/vine)	Yield (kg/m)	Pruning wt (kg/m)
2020	Dupee	2.7 (± 0.2)	3.7 (± 0.4)	1.5 (± 0.1)	0.5 (± 0.02)
	Saum	2.3 (± 0.4)	3.2 (± 0.3)	1.3 (± 0.1)	0.5 (± 0.02)
	Woodburn-Willamette	2.6 (± 0.1)	3.1 (± 0.5)	1.7 (± 0.1)	0.8 (± 0.03)
2021	Dupee	2.3 (± 0.1)	3.3 (± 0.2)	1.7 (± 0.2)	0.3 (± 0.02)
	Saum	2.1 (± 0.1)	3.3 (± 0.2)	1.6 (± 0.1)	0.2 (± 0.01)
	Woodburn-Willamette	2.4 (± 0.1)	3.7 (± 0.2)	2.1 (± 0.2)	0.6 (± 0.03)
2022	Dupee	2.1 (± 0.1)	2.5 (± 0.2)	1.0 (± 0.1)	0.7 (± 0.04)
	Saum	2.2 (± 0.1)	2.5 (± 0.2)	1.5 (± 0.1)	0.6 (± 0.04)
	Woodburn-Willamette	2.3 (± 0.2)	2.8 (± 0.2)	1.2 (± 0.1)	1.3 (± 0.07)

Means and (standard errors) are presented.

Table 3. Tissue nitrogen at bloom and véraison of Pinot noir growing in three soil types during three growing seasons (2020-2022).

		Bloom		Véraison	
Year	Soil	Leaf Blade	Petiole	Leaf Blade	Petiole
2020	Dupee	3.13 (± 0.28)	0.86 (± 0.03)	2.01 (± 0.07)	0.38 (± 0.02)
	Saum	3.17 (± 0.05)	0.91 (± 0.08)	1.90 (± 0.07)	0.34 (± 0.02)
	Woodburn-Willamette	3.56 (± 0.18)	1.14 (± 0.04)	2.44 (± 0.07)	0.40 (± 0.04)
2021	Dupee	3.17 (± 0.01)	0.84 (± 0.03)	2.14 (± 0.01)	0.49 (± 0.01)
	Saum	2.91 (± 0.01)	0.84 (± 0.03)	1.94 (± 0.11)	0.45 (± 0.005)
	Woodburn-Willamette	3.24 (± 0.07)	0.90 (± 0.012)	2.26 (± 0.25)	0.48 (± 0.04)
2022	Dupee	3.5 (± 0.10)	0.99 (± 0.07)	2.28 (± 0.02)	0.50 (± 0.005)
	Saum	3.2 (± 0.04)	0.96 (± 0.06)	2.01 (± 0.21)	0.44 (± 0.000)
	Woodburn-Willamette	3.7 (± 0.00)	1.3 (± 0.18)	2.36 (± 0.16)	0.51 (± 0.04)

Means are presented and (standard errors) are presented.

Table 4. Harvest berry ripeness of Pinot noir growing in three soil types during three growing seasons (2020-2022)

Year	Soil Type	TSS (Brix)	pH	TA (g/L)	Sugar/berry
2020	Dupee	23.5 (± 0.2)	3.23 (± 0.04)	7.7 (± 0.3)	0.20 (± 0.01)
	Saum	24.3 (± 0.2)	3.44 (± 0.05)	6.0 (± 0.4)	0.21 (± 0.01)
	Woodburn Willamette	22.6 (± 0.3)	3.27 (± 0.07)	7.3 (± 0.4)	0.16 (± 0.01)
2021	Dupee	24.1 (± 0.4)	3.21 (± 0.02)	6.8 (± 0.25)	0.19 (± 0.01)
	Saum	25.3 (± 0.4)	3.37 (± 0.02)	6.0 (± 0.14)	0.21 (± 0.01)
	Woodburn Willamette	23.8 (± 0.3)	3.20 (+ 0.03)	7.2 (± 0.27)	0.24 (± 0.01)
2022	Dupee	23.9 (± 0.2)	3.30 (± 0.02)	8.3 (± 0.2)	0.20 (± 0.01)
	Saum	24.7 (± 0.3)	3.47 (± 0.04)	7.1 (± 0.2)	0.25 (± 0.01)
	Woodburn Willamette	23.0 (± 0.3)	3.30 (± 0.03)	8.8 (± 0.2)	0.26 (± 0.01)

Means are presented and (standard errors) are presented.

Figures

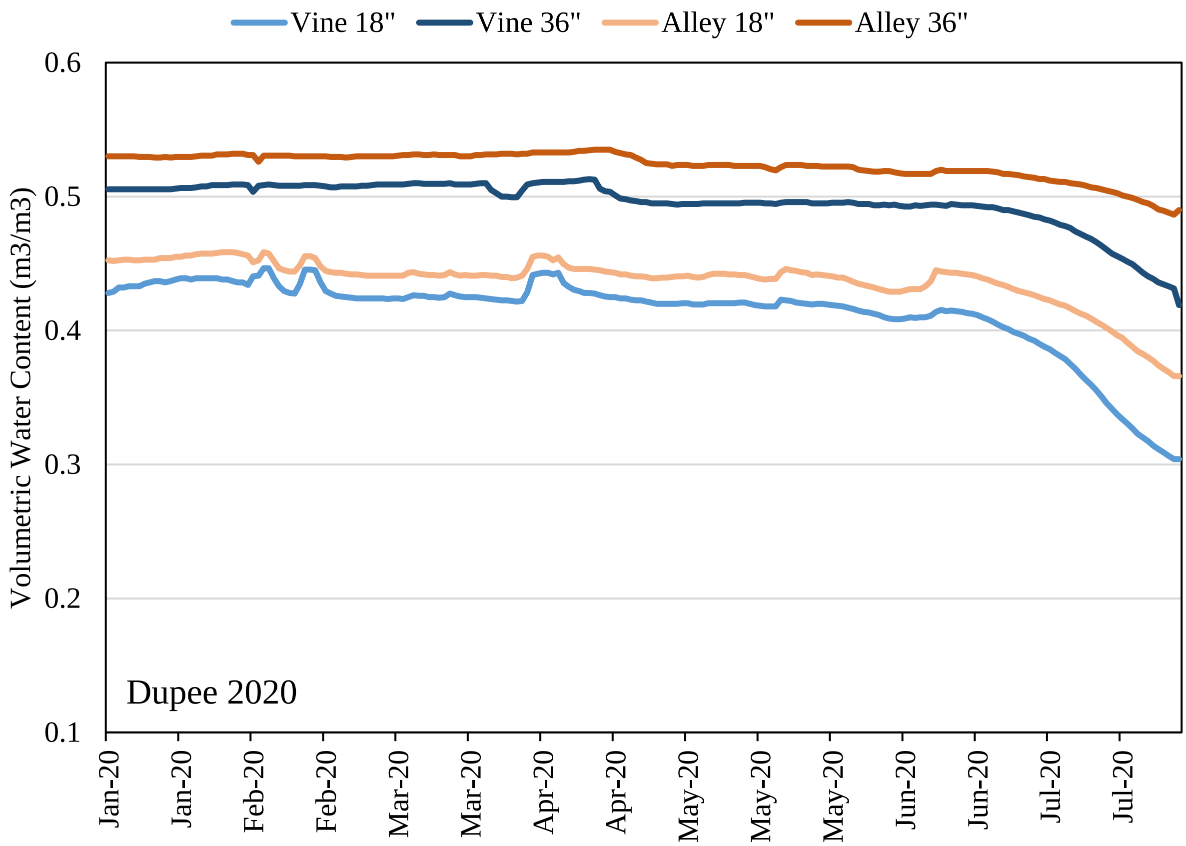

Figure 1a. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Dupee soil from 1 Jan 2020 to 31 Dec 2020 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18” (46 cm) and 36” (91 cm) depths.

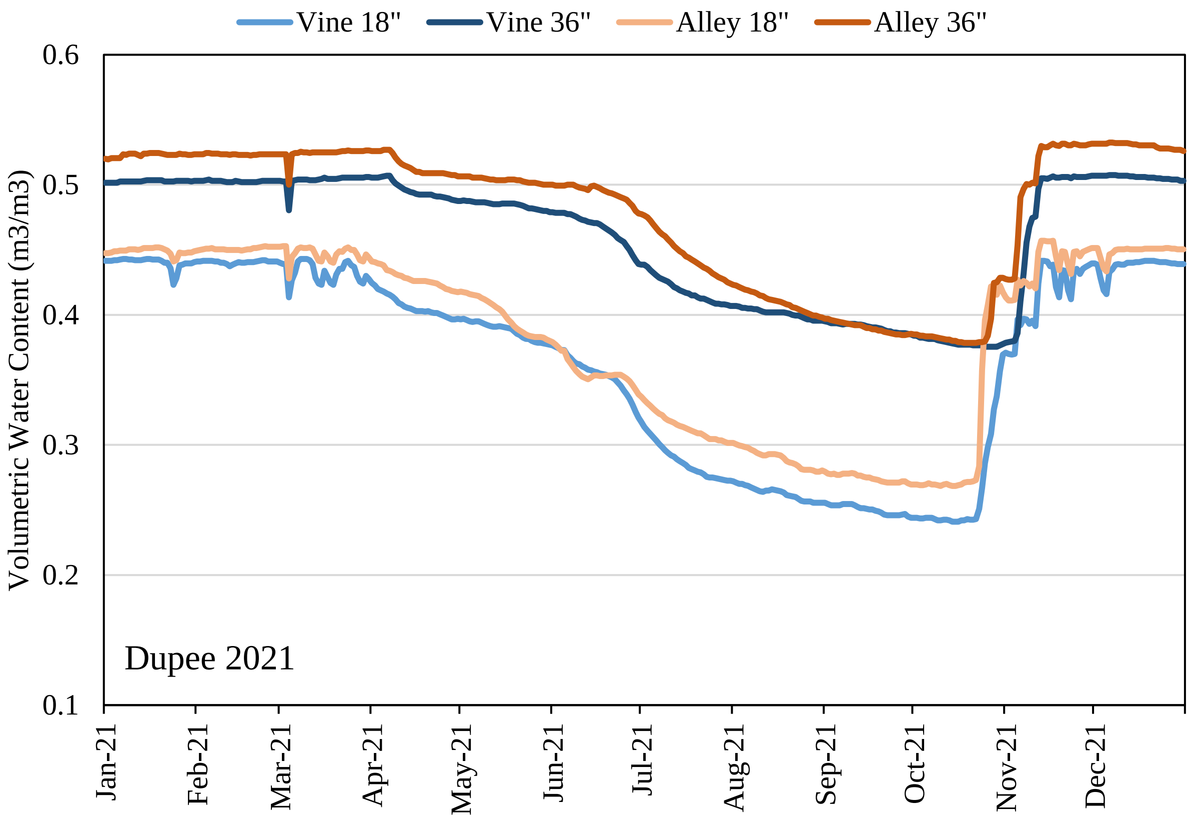

Figure 1b. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Dupee soil from 1 Jan 2021 to 31 Dec 2021 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18" (46 cm) and 36" (91 cm) depths.

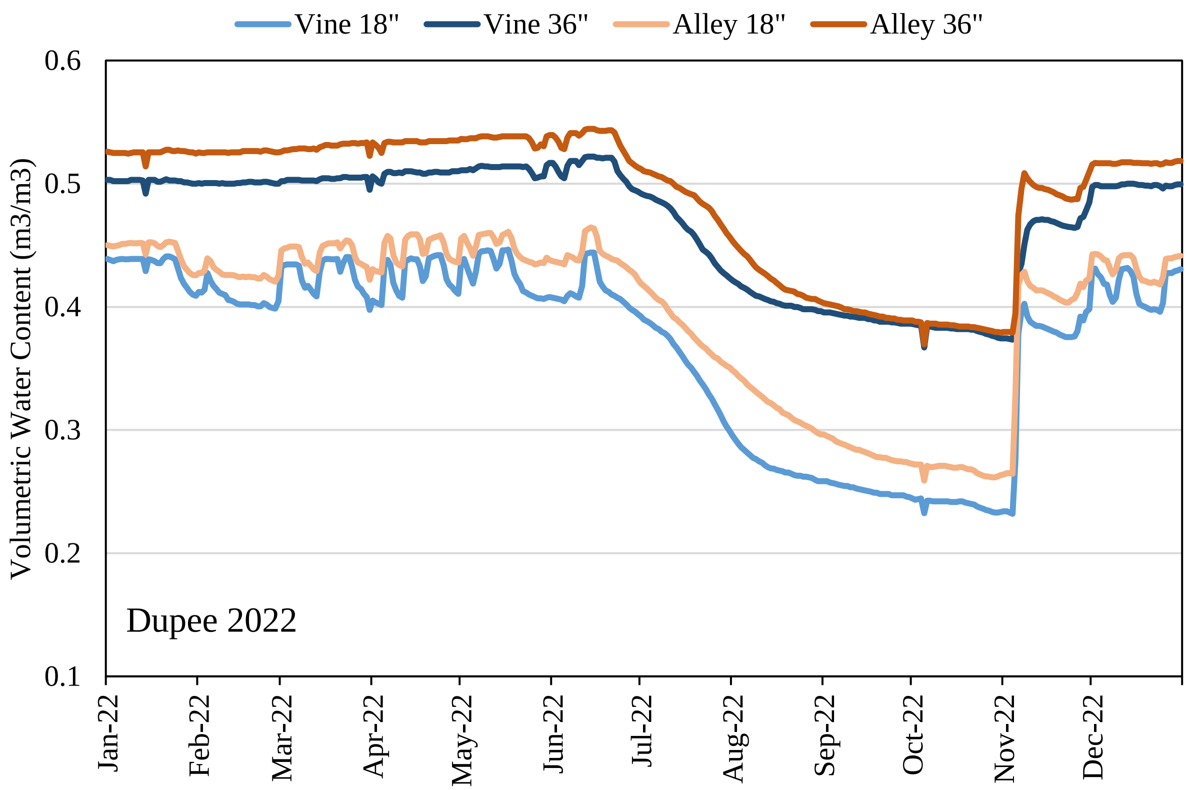

Figure 1c. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Dupee soil from 1 Jan 2022 to 31 Dec 2022 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18" (46 cm) and 36" (91 cm) depths.

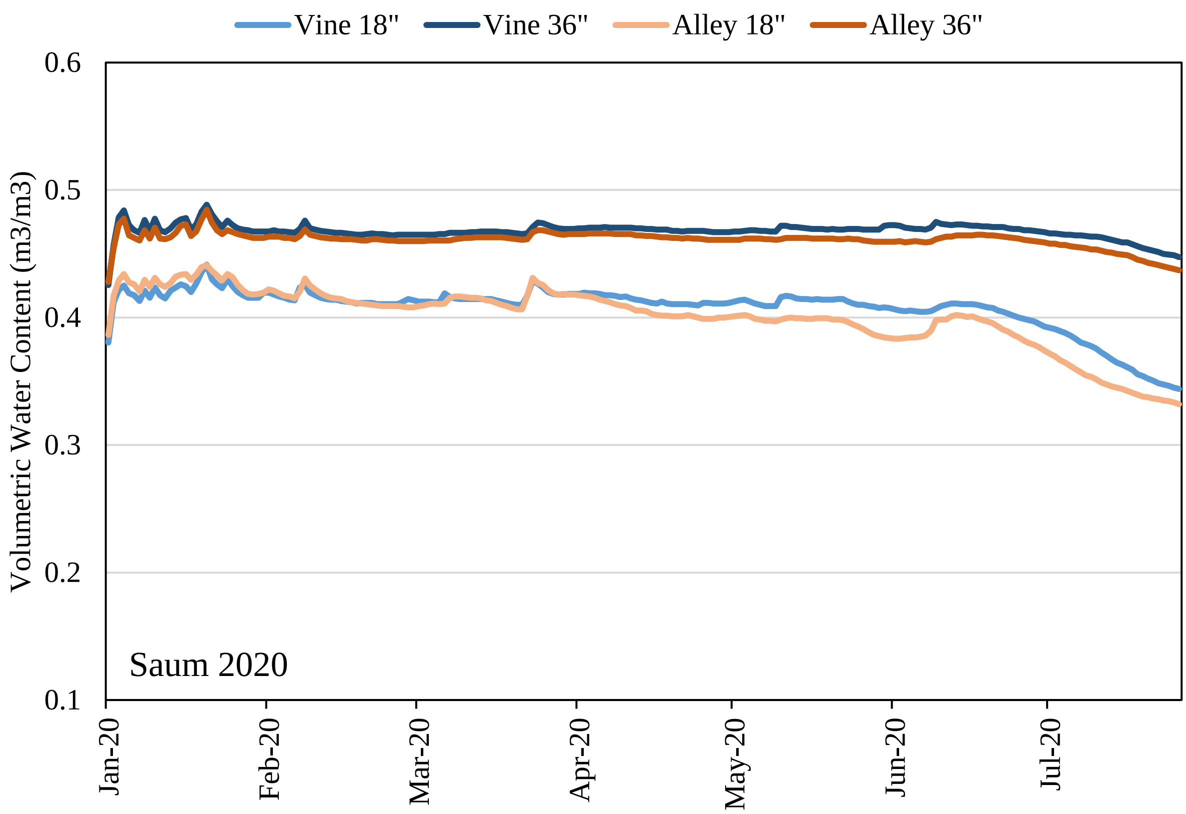

Figure 1d. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Saum soil from 1 Jan 2022 to 31 Dec 2022 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18" (46 cm) and 36" (91 cm) depths.

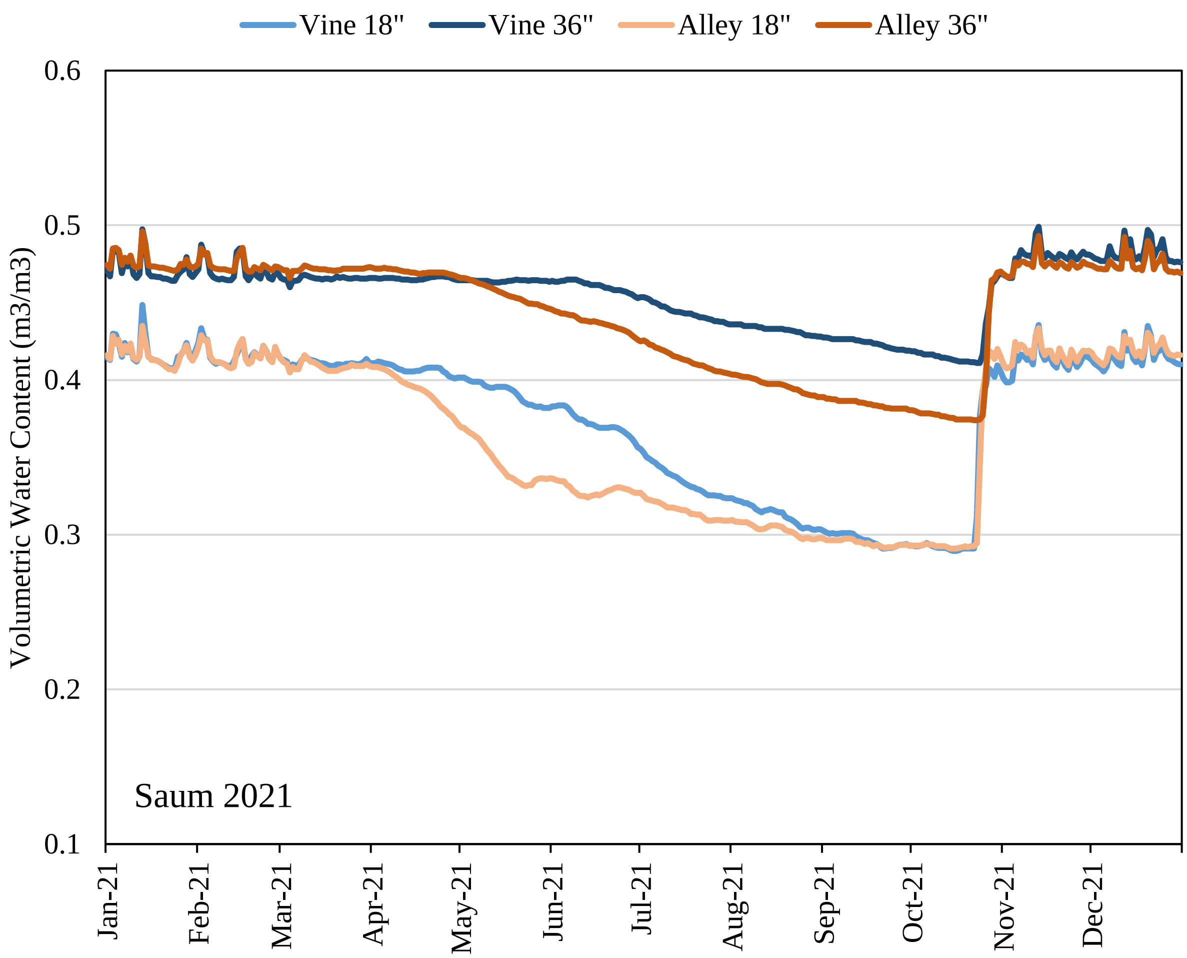

Figure 1e. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Saum soil from 1 Jan 2021 to 31 Dec 2021 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18” (46 cm) and 36” (91 cm) depths.

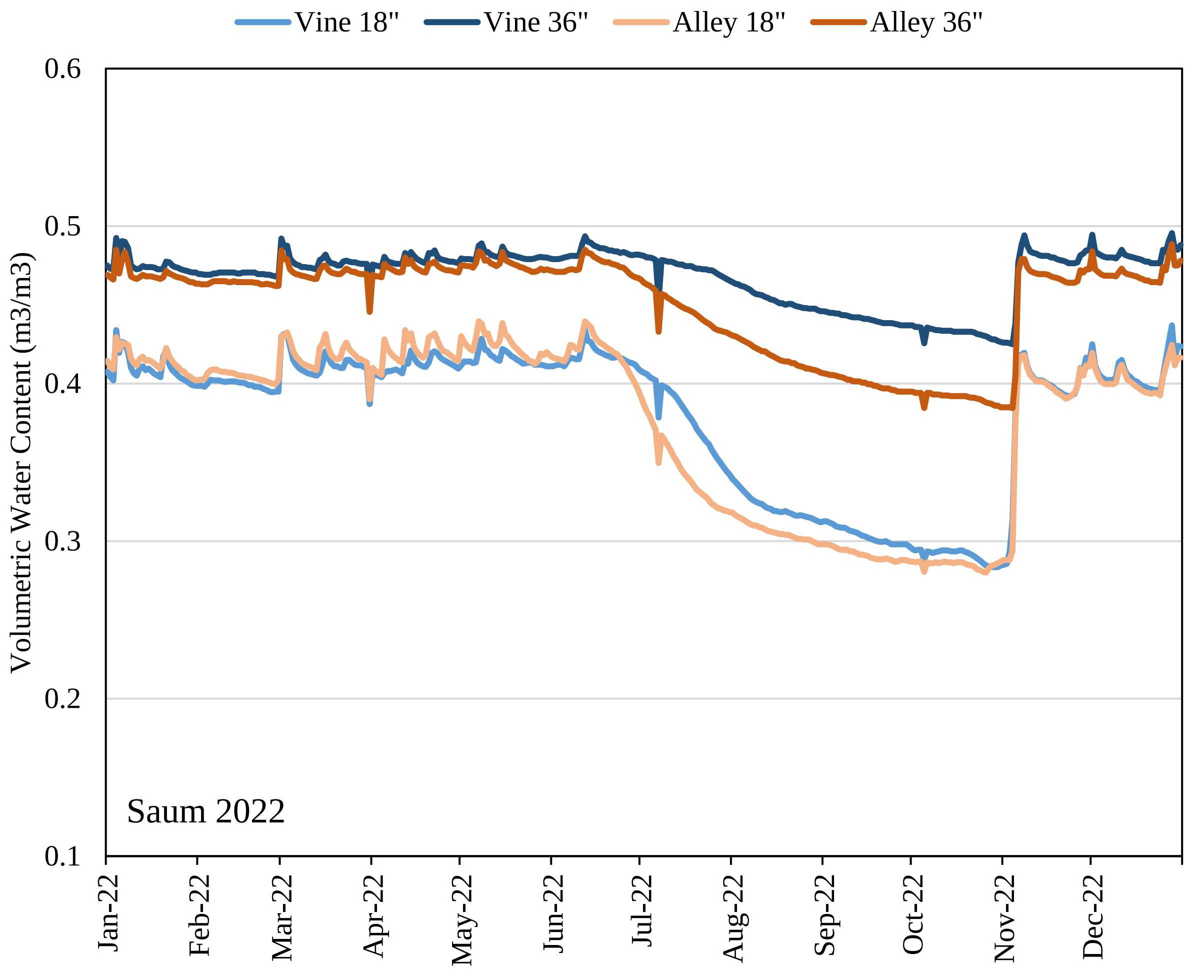

Figure 1f. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Saum soil from 1 Jan 2022 to 31 Dec 2022 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18” (46 cm) and 36” (91 cm) depths.

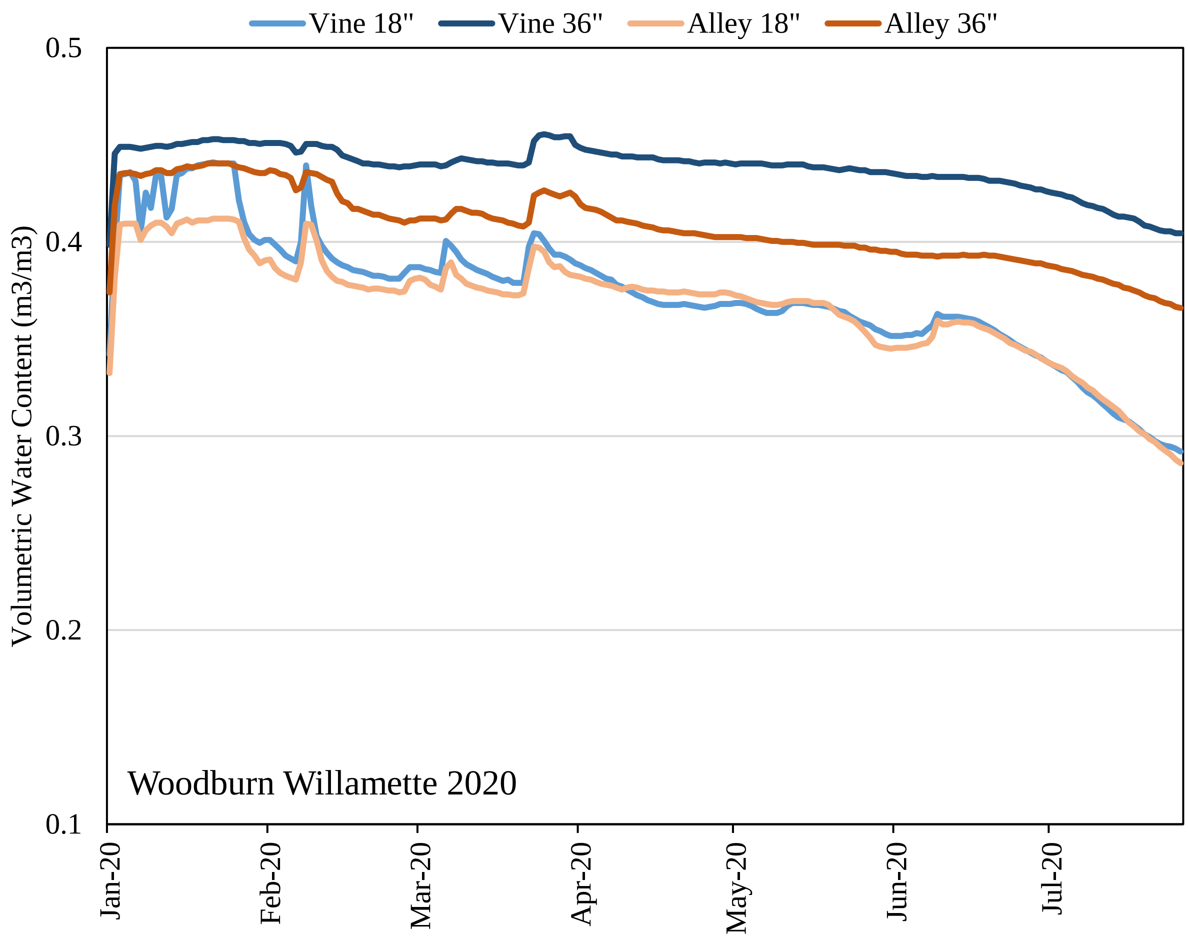

Figure 1g. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Woodburn Willamette soil from 1 Jan 2020 to 31 Dec 2020 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18” (46 cm) and 36” (91 cm) depths.

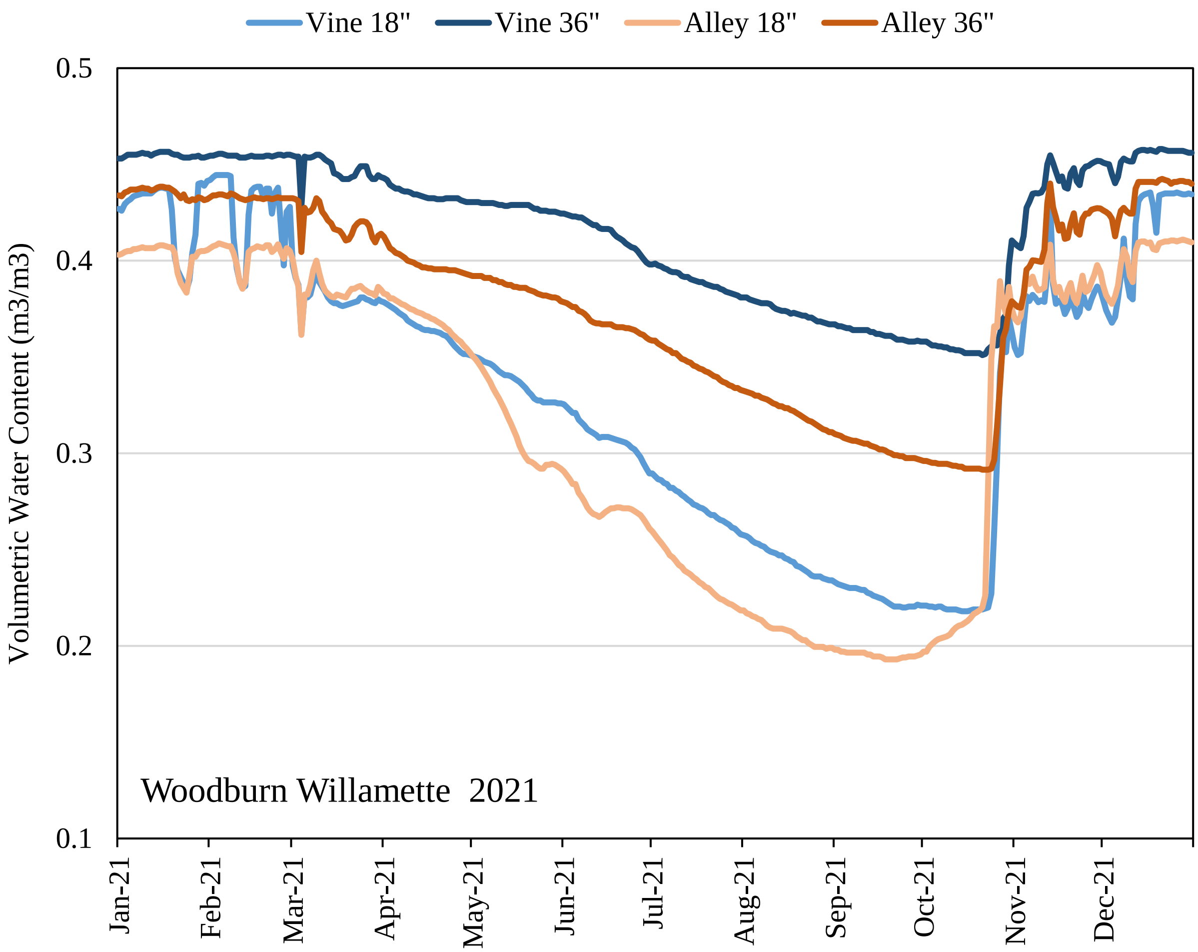

Figure 1h. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Woodburn Willamette soil from 1 Jan 2021 to 31 Dec 2021 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18" (46 cm) and 36" (91 cm) depths.

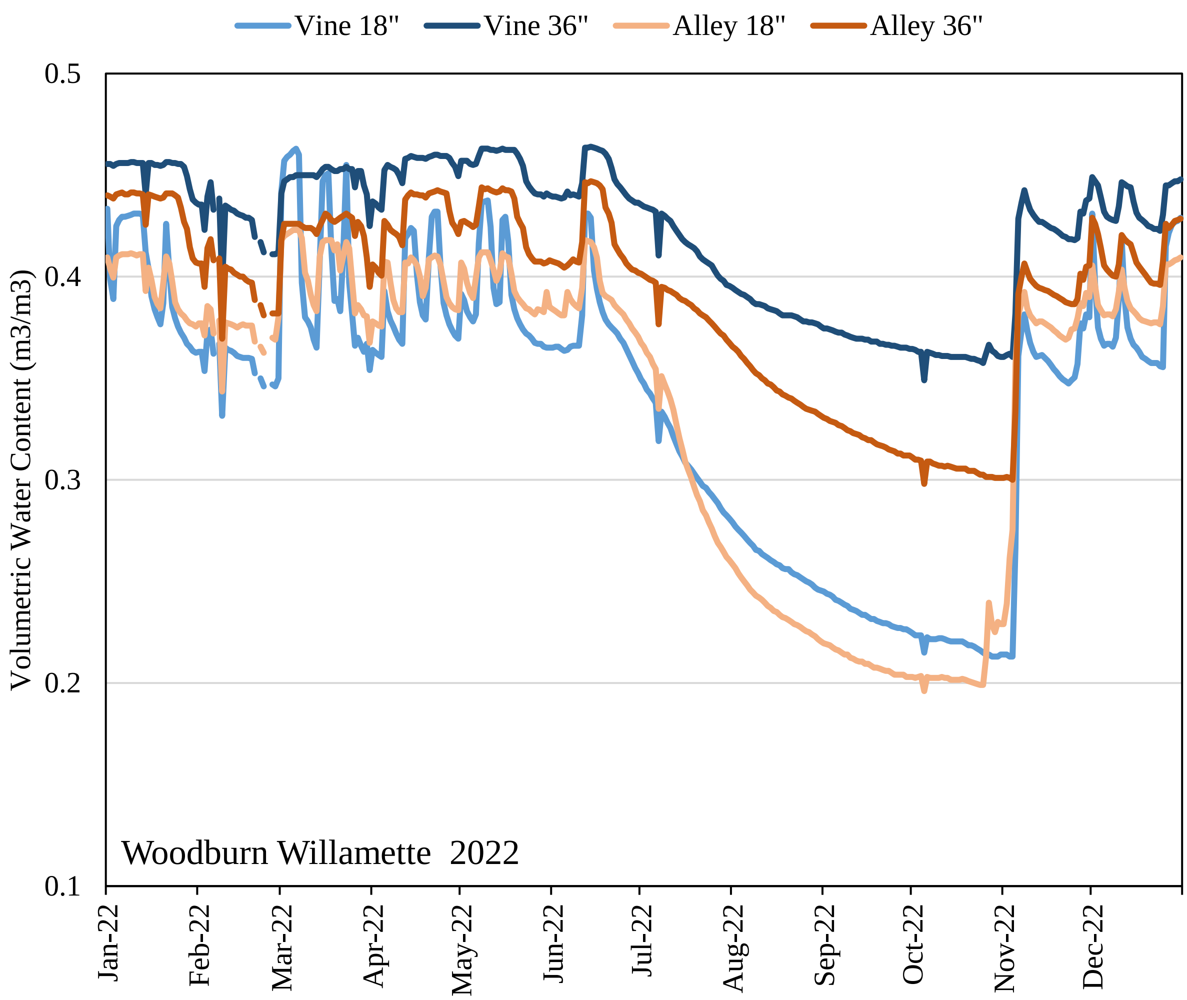

Figure 1i. The daily average soil moisture (volumetric water content in m^3/m^3) of two sensor locations in Woodburn Willamette soil from 1 Jan 2022 to 31 Dec 2022 in a Pinot noir vineyard in Newberg, OR. Sensors were located under-vine within the vine row (shades of blue) and in the mid-alley (shades of brown and orange) at 18" (46 cm) and 36" (91 cm) depths.

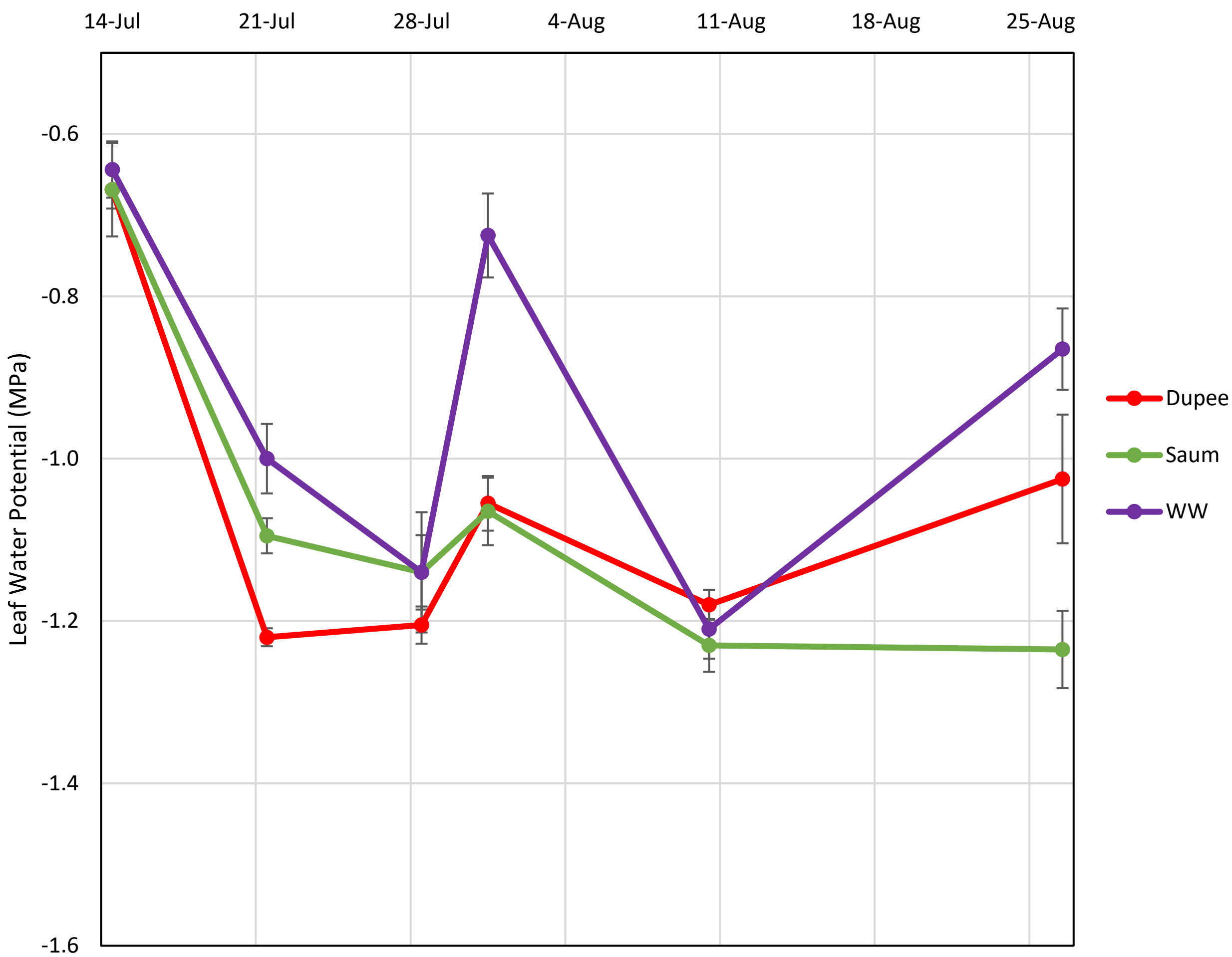

Figure 2a. Midday leaf water potential of Pinot noir growing n three soil types in a vineyard in Newberg, OR during 2020. Data are means (± standard error).

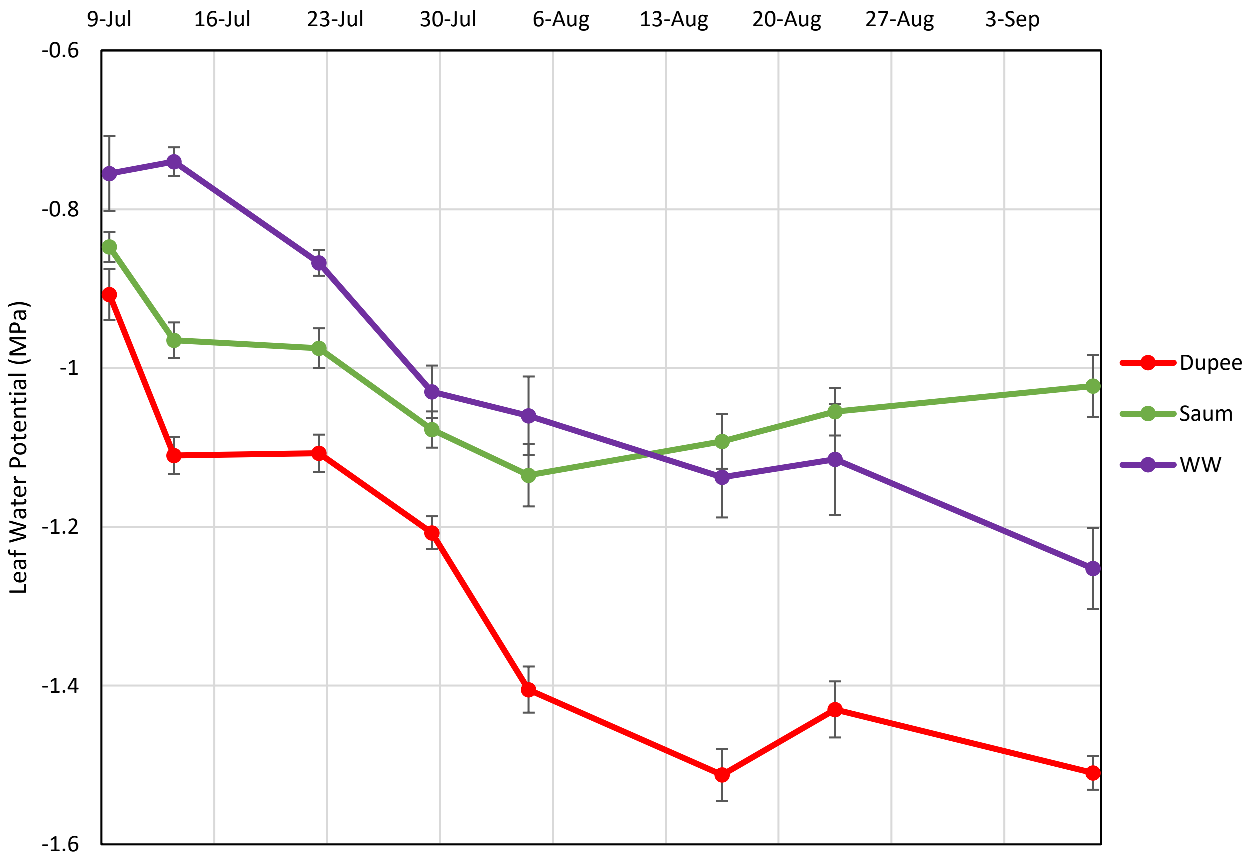

Figure 2b. Midday leaf water potential of Pinot noir growing in three soil types in a vineyard Newberg, OR during 2021. Data are means (± standard error).

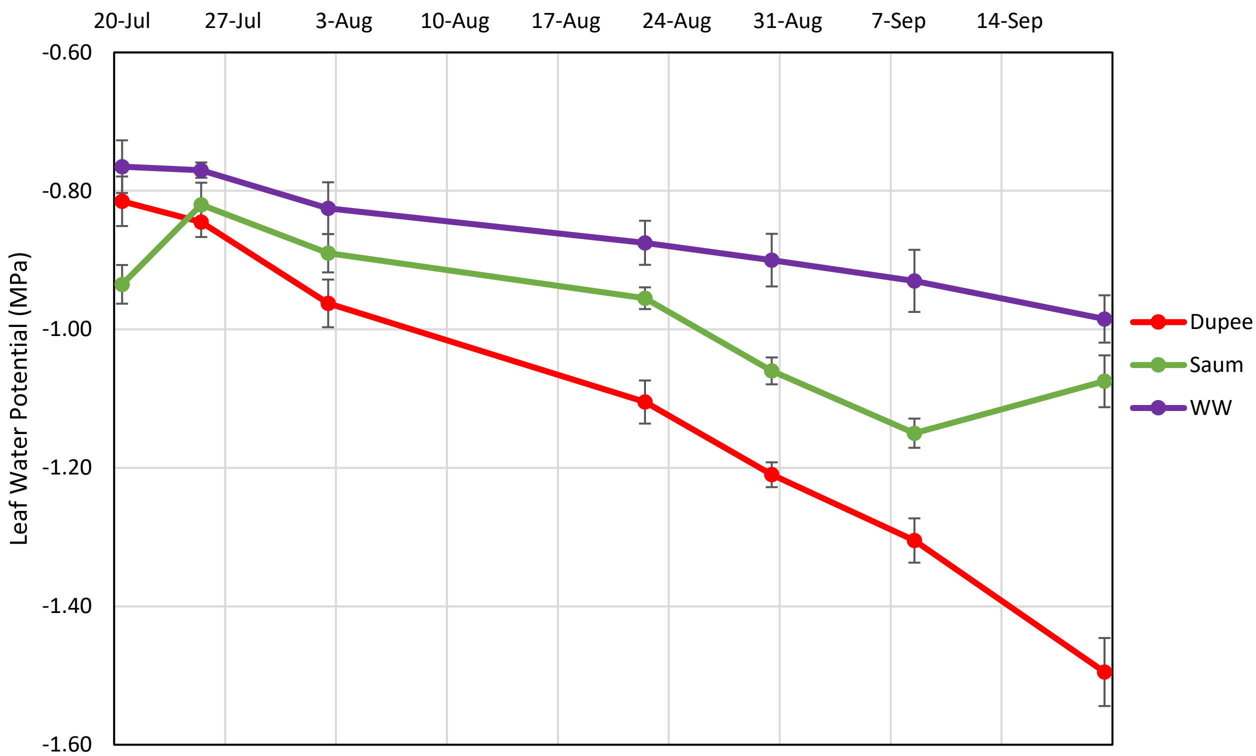

Figure 2c. Midday leaf water potential of Pinot noir growing in three soil types in a vineyard in Newberg, OR during 2022. Data are means (+ standard error).